

10. CENTRAL HARDWARE AND SOFTWARE

As discussed in Chapter 4, the architecture for the Boston metropolitan region is a distributed, organization-based structure. Each transportation agency (e.g., MHD, MBTA, MTA, MassPort, State Police, local jurisdictions, etc.) monitors and operates its respective facilities via an agency-specific Transportation Operations Center (TOC). The regional Transportation Information and Coordination Center (TICC) provides fusion of data from the TOCs, coordinated incident management, and strategic operations (and possibly control) in accordance with pre-approved plans during situations with regional impacts.

The overall architecture and system functions indigenous to the different types of control centers is diagrammed in Exhibit 10-1. Summarizing:

- The regional IVHS network centers around the collection, evaluation, and dissemination of traveler information -- both pretrip and enroute. The local TOCs collect data from their respective detection devices and other resources - both automated and manual. This information is used to monitor conditions on their facilities and to develop and implement appropriate strategies.
- These data are also passed automatically to the TICC, where it is merged with data from other TOCs to provide a region - wide clearinghouse. This traveler information database is based on a geographic information system (GIS), thereby providing a common reference for the large volume of spatial data and for correlating position - related information obtained from disparate sources (e.g., *SP, detectors, etc.).
- The traveler information data base resident at the TICC -- which includes graphic, text, and video displays -- can be called up by any TOC or private entity. The user - selectable information is presented through a Graphical User Interface (GUI), supported by audible and/or visual alerts to allow operators to monitor the system while carrying on their other tasks.
- An Expert System (resident at the TICC) will continuously look for anomalies in the collected information which might indicate a problem, determine the potential impacts of these problems on the region's transportation network, identify response strategies (in accordance with pre-approved baseline plans), and submit these actions to agency - specific TOCs for implementation. Response plans will be dynamic in nature in that the baseline response plans will be automatically tailored to real-time conditions and updated over the duration of the condition.

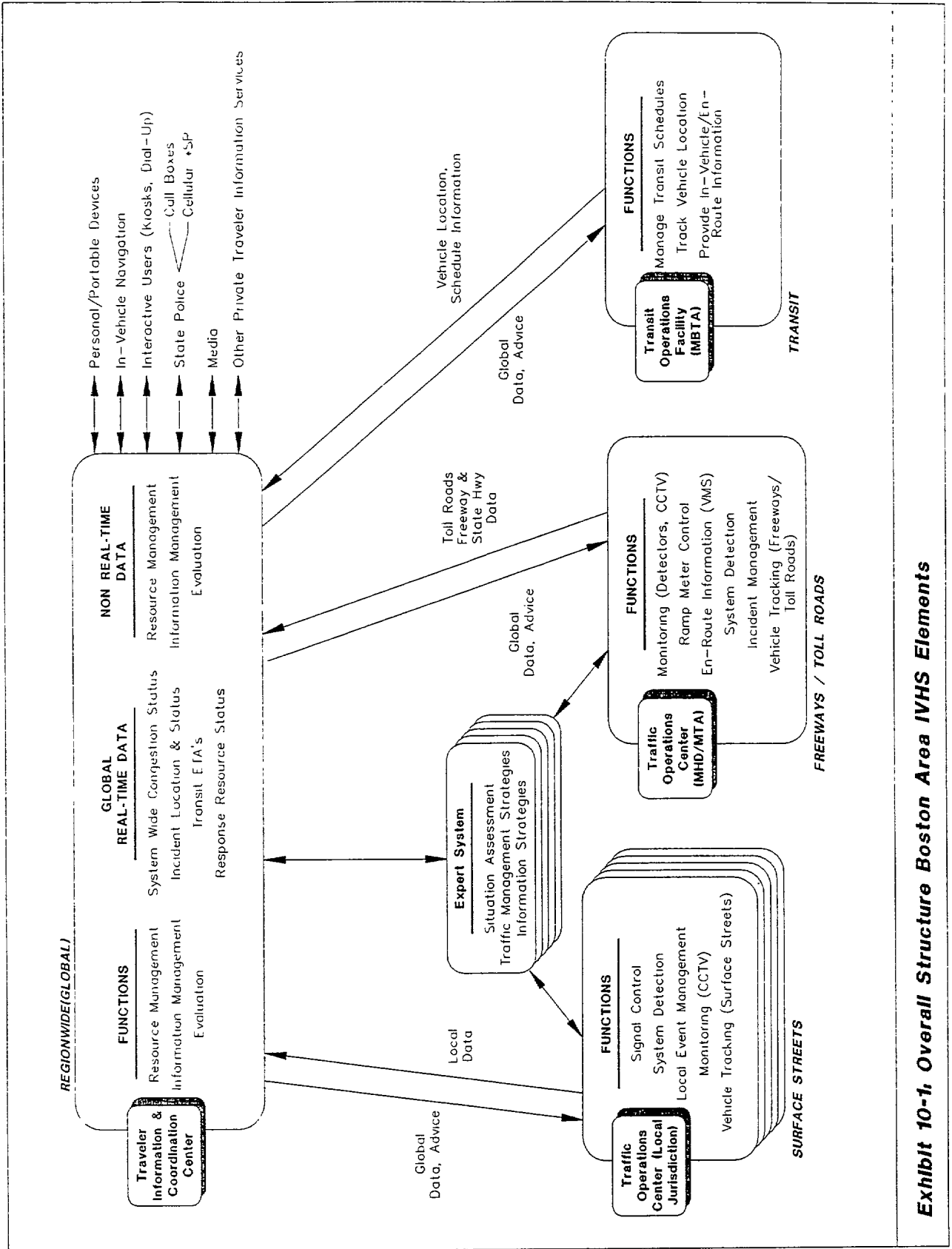


Exhibit 10-1. Overall Structure Boston Area IVHS Elements

- Institutional considerations may also permit the TICC to monitor and/or control traffic operations for another agency depending on the nature of the problem and that agency's resources.

The ultimate goal of the central architecture is to provide a mechanism whereby software and hardware elements can be implemented to allow the various subsystems and TOCs to share information and decision support via the TICC. As discussed herein, this central architecture -- for both the regional TICC and the MHD TOC -- is built around real-time data distribution via a client-server model, integrated workstations utilizing a graphical user interface, geographical information systems, and decision support via expert systems.

The recommended architecture for the central hardware and software represents a significant effort. Moreover, given the dynamic nature of technology and the need for preapproved response scenarios covering a wide area, the implementation of the TICC-centered network will be a continually evolving process. Nevertheless, the hardware and software elements recommended herein are available, and they are currently being implemented and operated in freeway traffic management systems and area-wide networks such as the "Smart Corridor" in Los Angeles. It is recommended that all of the basic architecture elements -- database organization, GUI, GIS, Expert System, FTMS software -- be included in the Phase 1 implementation, with continuing expansion and enhancements throughout the Year 2000 implementations.

DATABASE ORGANIZATION AND DISTRIBUTION

Data fusion requires timely distribution of real time data over the network. The regional TICC will require that a combination of dynamic data (e.g., link volumes/travel times, transit schedule adherence, VMS messages, incident reports, weather conditions, equipment status) and static data (response plans, VMS libraries, timing plans, construction and special event schedules, etc.) be universally available throughout the network. The regional IVHS architecture is based on a "global scheme multi-database" model. The global system (i.e., the regional TICC) accesses local (i.e., TOC) data through an external interface of the local database management systems. This model is relatively heterogenous, allowing the local TOCs to be as different as necessary to support their local missions. It also allows

for graceful integration of existing systems and their databases. The unified view of the regional data is provided by the global scheme at the TICC, with each local system making global queries through the TICC.

The local TOC systems will be collecting and processing data within their own databases. When data arrives that is required by the global TICC system, each local system will convert that data to the form required by the global traveler information database and transmit the data to the TICC. When the data arrives at the global TICC database, it becomes available to the entire network immediately. It is important to note that the global database design does not necessarily dictate the design of the local TOC databases. Differences between the local TOC and global TICC database definitions are accommodated during the conversion phase of data forwarding.

Distribution of dynamic data is a very significant issue in a large system such as the Boston area IVHS network. When a TOC posts updated data to the TICC global database, that data is immediately available for access by other agency-specific systems. However, these other TOC's may not be aware that the data has arrived. Since user displays are to be dynamically updated, it will be necessary for each user interface process to obtain the updated data. Two approaches may be used to address this issue. Processes may poll the global database on a periodic basis to obtain updated data, or the global database may inform interested processes when new data has arrived. The second approach, known as event-driven processing, is more efficient and generally leads to more timely display of dynamic information.

It is recommended that an event-driven approach be taken for dissemination of real-time dynamic data throughout the Boston IVHS network. Under this type of architecture, each local TOC process that requires real-time data will register for notification when data changes. The use of the global database at the regional TICC for the collection of systemwide data leads to significant simplifications in the structure of this data distribution mechanism. Taking advantage of the hierarchical nature of the system, TOC-collected data registers with its local server, which in turn registers with the global system at the TICC. When a change occurs at the global level, the data is passed to the various local servers at the TOCs for distribution to their individual networks. This minimizes network traffic between the global TICC and the local agency-specific systems, making the most effective use of network

resources.

During system design, the structure of the TICC will be developed to provide maximum compatibility with any existing TOC databases. The contents of the global TICC database will also be defined (e.g., should the global database know all the train locations, or the schedule adherence of each line and extent of any delays). At that time, data will be segregated into static and dynamic components. Service distribution types will be defined for the dynamic data, and analysis will be performed to ascertain the types of distribution services that will be required for each type of dynamic data.

Client-Server Model

It is recommended that the Boston area M-IS network use the client-server model to facilitate the communication and integration between disparate agency-specific systems and platforms, aid the development of new systems and interfaces, enhance the expandability of the system, and provide a common mechanism for systems to distribute and share information. Exhibit 10-2 shows an example of client-server architecture.

A client-server system is composed of one or more clients and one or more servers. In this system, a client gathers information required for queries or commands that will be presented to the server. It constructs queries or commands in a predefined language for presentation to the server. The client presents the command or query to the server and collects the results. The client will then often process the data that is returned from the server.

A server provides a service to the client. The nature of a service is very general, and it may include data retrieval, message distribution, data distribution, data processing and analysis, hardware interface and control, etc. A server responds to client queries and does not initiate communications with a client. Typical servers which meet these criteria include data base servers, VMS interface servers, data gathering and acquisition servers, network printer servers, and network communications servers.

For the Boston IVHS regional network (refer to Exhibit 10-3), a local system server will be added and connected to the central hardware at each agency-specific TOC. These TICC servers will interface with the agency system processors, gather information available

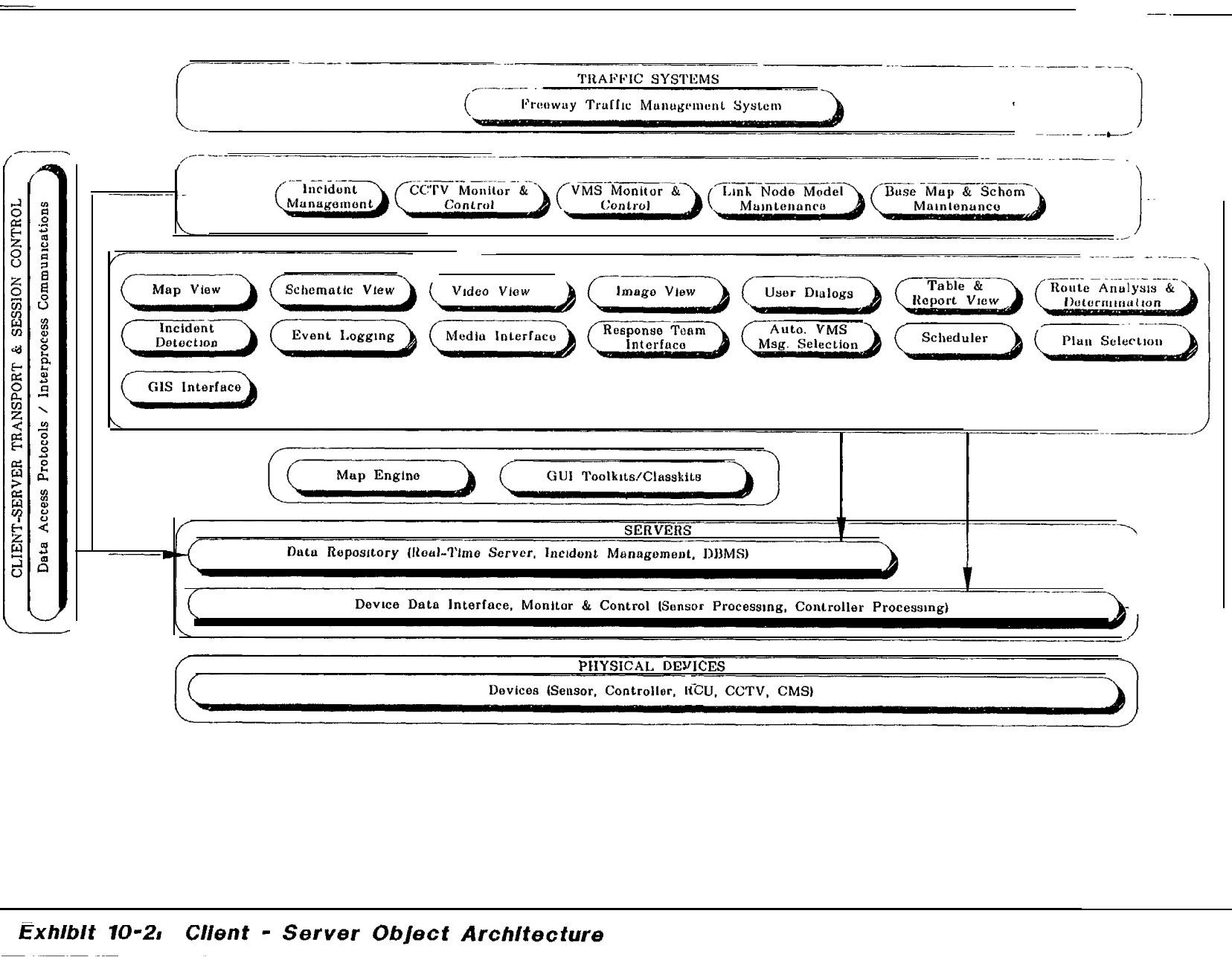


Exhibit 10-2: Client - Server Object Architecture

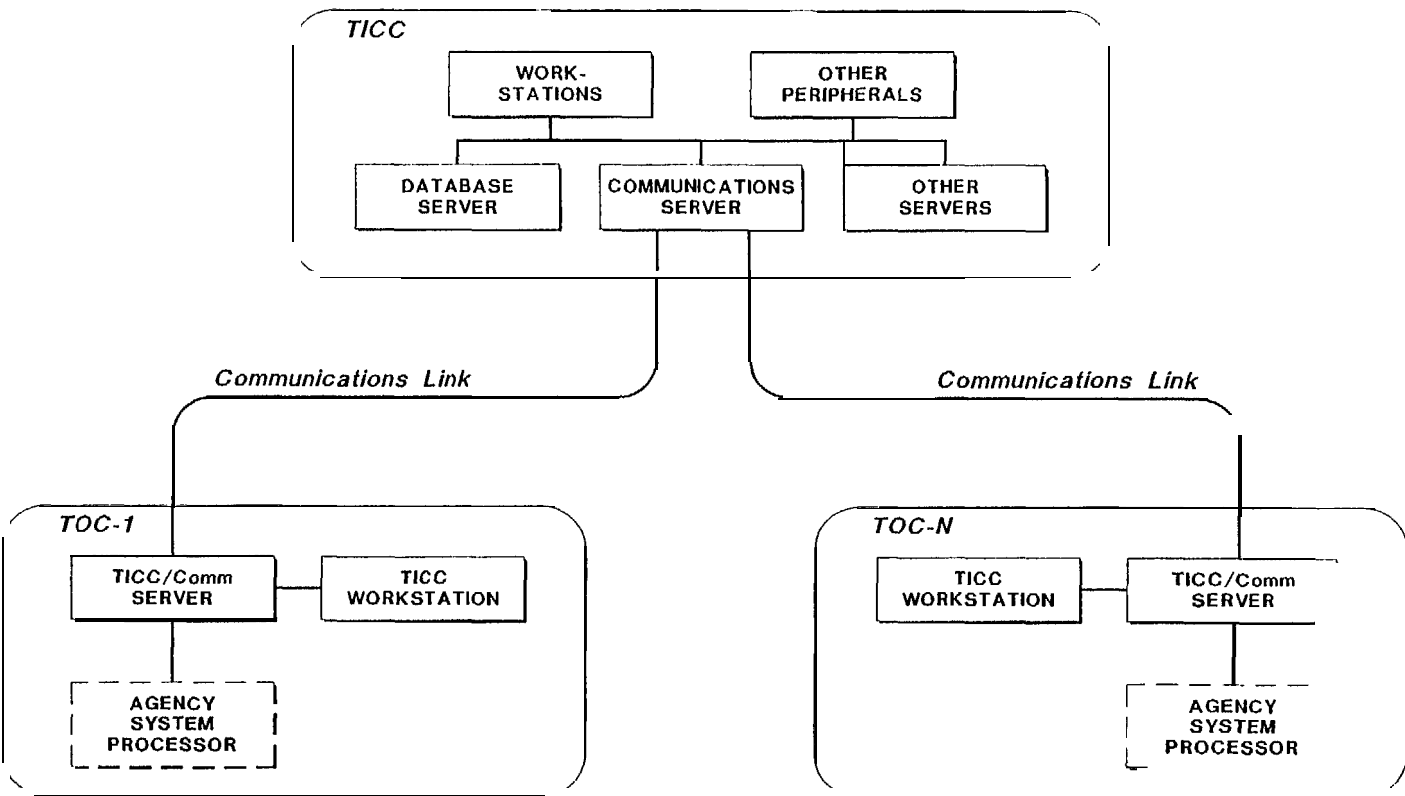


Exhibit 10-3. Regional Configuration of Servers

from the local databases, convert it to a standardized global protocol, and interface with workstations located at the agency-specific TOC's. This architecture allows each agency to maintain the appropriate degree of autonomy and control, while still integrating it into the overall IVHS network.

At the heart of the network will be two servers located at the TICC. One will primarily perform intensive database input/output, and the other will manage communications with the agency-specific systems. The data base server will keep most, if not all, of the dynamic data concerning roadway condition, incidents and transit operations, as well as any static information about the system such as VMS locations, intersection locations, CCTV camera configurations, etc. The data base server will insure that information is stored and accessed in a consistent manner for distribution throughout the network. This server will process the data into a format that can be displayed on integrated workstations throughout the region -- the goal being to present information from a variety of sources in a consistent view.

Communications servers will be provided that support the communications backbone of the distributed system. The communications server at the TICC and the TICC server at each TOC will include communications elements to help support broad band communications, support data queries to and from the TICC database and other servers, and provide a mechanism for expandability of the system both in terms of numbers of workstations at any one location and the number of TOCs in the network.

In essence, the servers will act as bridges between the TICC and the agency-specific TOCs, thereby limiting traffic on the local area networks. Moreover, by using a standard network protocol and open systems design, IVHS data and traveler information will be transported throughout the region -- between the TICC and agency-specific TOCs and private entities -- using a combination of event-driven and direct data requests. It will be the "job" of each server to format this data for general transfer.

Database Management Standards

The Boston area IVHS network will require use of Database Management Systems (DBMS) in the heterogenous networked environment. Consistent interfaces between

networked clients and servers will be required, allowing clients and servers to exist on different platforms. Data interchange services will be required to handle the exchange of data between different platforms.

Basic database services include the ability to access data and to perform searches based on potentially complex sets of conditions. Other operations include inserting, deleting, and updating records. The Database Management System must also provide facilities to ensure data integrity. Facilities must also exist to translate between data representation across platforms. As an example, the representation for a double precision floating point number on a VAX is very different from that on a Sun, and the database services must account for those difference when clients and servers communicate.

One potential standard is the SQL standard (ISO 9075:1982). Many database products support the standard SQL interface. A variety of other products include the SQL interface to allow data to be imported from databases. SQL should enable the use of many available software packages for database interaction. Even in a worst case scenario, where two database management systems (DBMS) will not interact, the SQL user interface may be used as bridge between the DBMSs. All SQL commands and data may be expressed as ASCII character strings. Thus, a client/server pair could be constructed to build the strings, transmit them across the network, feed the strings to the SQL user interface, accept the returned data, and transmit the data back to the client in string form. The string format, while somewhat crude, eliminates the issues of bit and byte ordering in most cases.

Database Security

System security software must be incorporated into the Boston area IVHS architecture to handle the potential conflicts between the responsibilities and liabilities of the individual TOCs and the needs of the regional TICC and the desires of private entities. Although the IVHS design promotes data sharing between and among the many agencies, each local agency will remain in control of what "private" data is made available throughout the network. The system design must strike a balance between the regional needs and any restrictions imposed by the individual agencies.

Data security issues must deal with database access (read only), database changes

(update), equipment control (variable message signs, signal timing plans), and system access (authorization of users). What privileges will be granted to each user or class of users must be determined, and a hierarchy of log-on procedures, and passwords, and privileges must be established to protect the databases and to prevent unauthorized control and operations.

CENTRAL HARDWARE

Computer processing capability has shown a doubling of performance every 18 months for the last 15 years. Moreover, the increasing sophistication and miniaturization of the processing components has shrunk the physical space which this processing capability requires by a factor of 100. There is no evidence that this trend is slowing, and most industry experts expect that the trend will continue for at least the next 10 years. Thus, any specific recommendations regarding the computer hardware for the regional TICC and the MHD TOC would be outdated in a matter of a few months. These considerations point up the importance of adopting a hardware/software structure and computing platform which is upwardly expandable, thus allowing gradual improvements in hardware efficiency and functionality as newer technology becomes available. The proposed architecture for the TICC central hardware and the MHD FTMS central hardware is shown in Exhibits 10-4 and 10-5, respectively.

Servers

With the modular architecture, much of the IVHS processing is distributed among workstations and field processors. Nevertheless, a centralized approach is recommended for managing the large real-time database, as well as for data storage to support the GUI for the advanced user interface and expert systems for decision support. The large centralized data server can provide fast response to the multiple users who will often access the system simultaneously. The use of GIS technology also necessitates the establishment of a centralized database manager. Field events and periodic data can then be made available throughout the system from this central point using the transaction capability of the central TICC server.

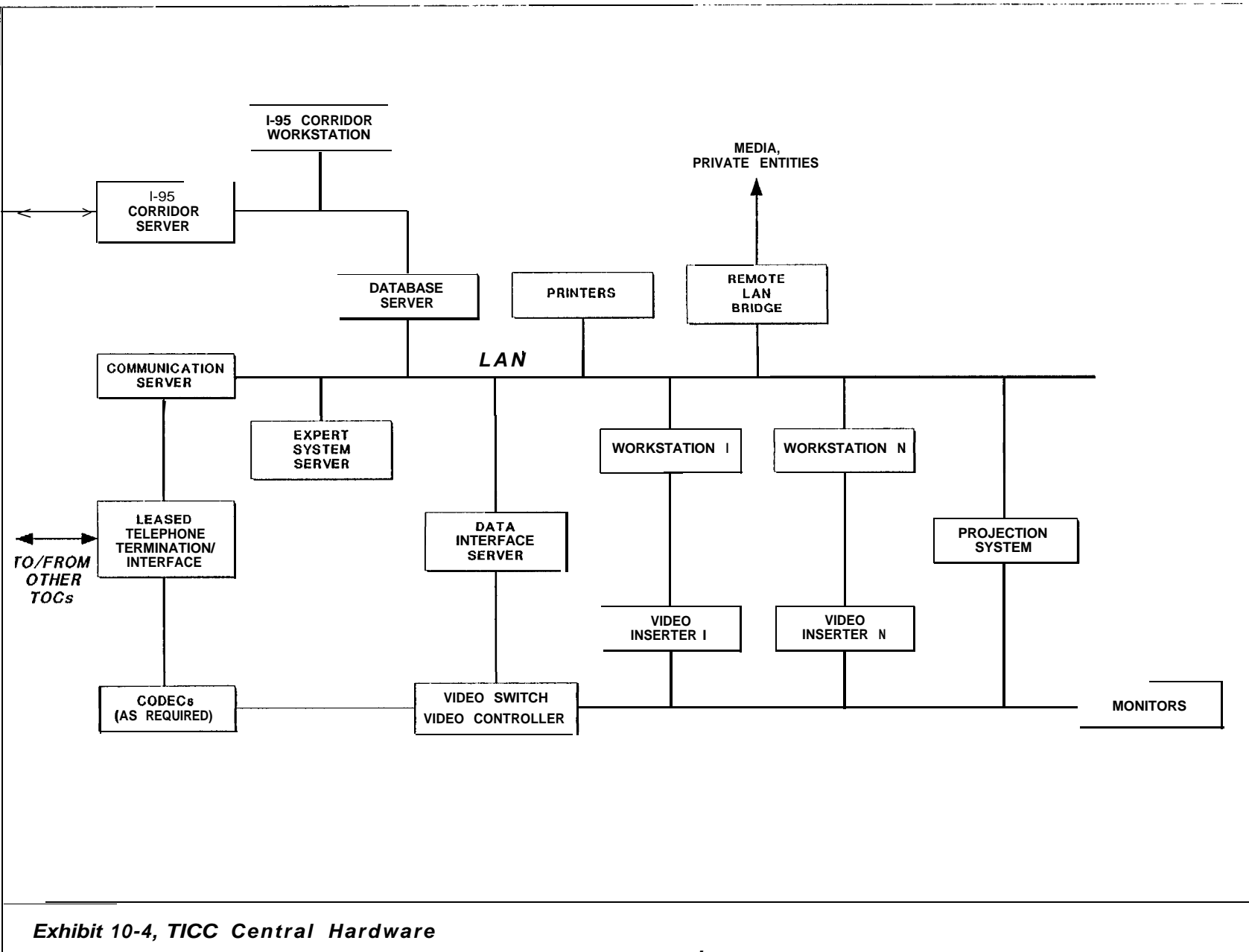


Exhibit 10-4, TICC Central Hardware

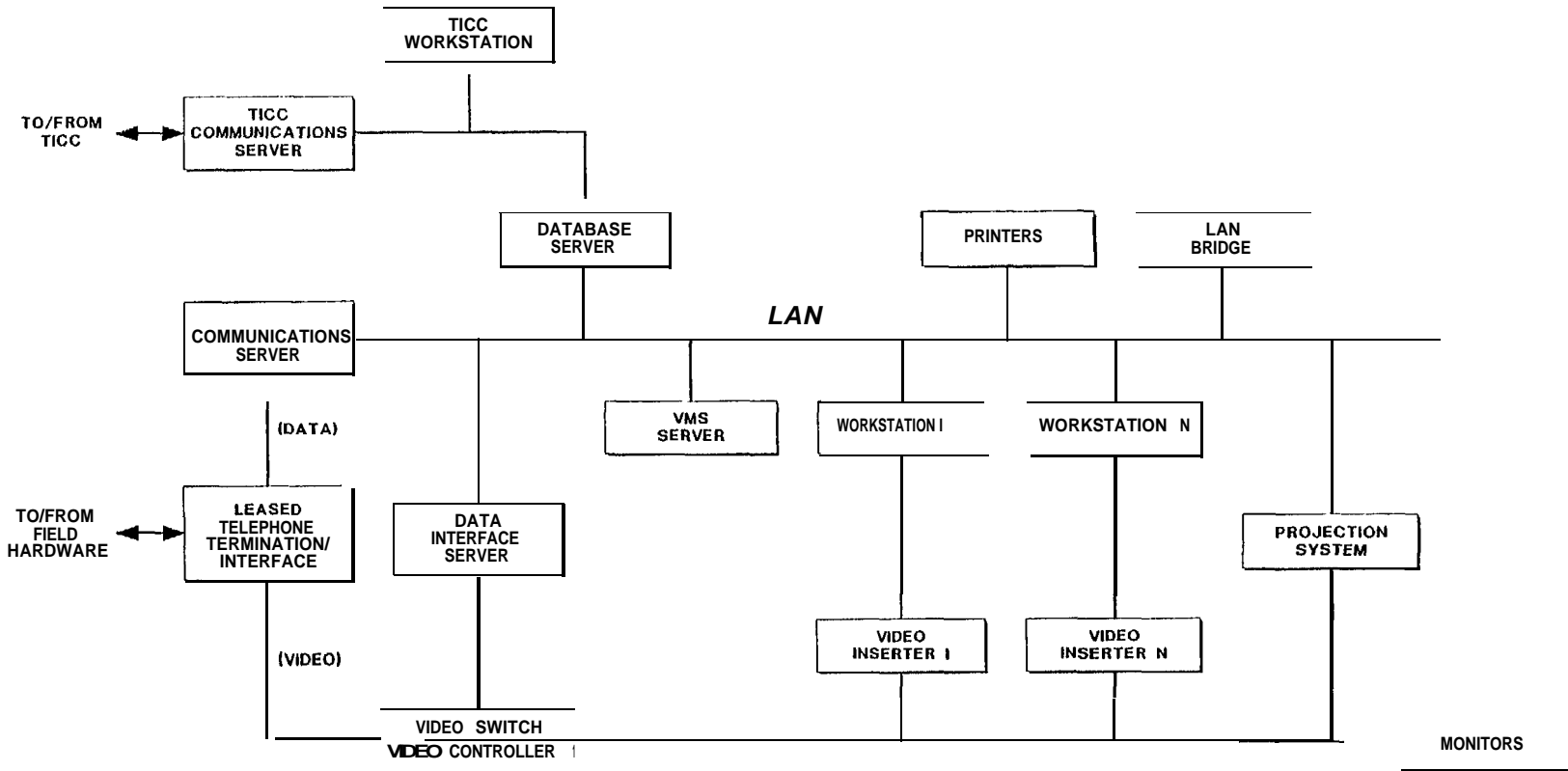


Exhibit 10-5 MUD Central Hardware Configuration

The database server and the data interface server will function as the central processor hardware -- processing and storing data, distributing this information to the various workstations as required, and coordinating the overall activities of the various system components. The database information will be distributed between them -- with the static and slowly varying portions on the database server, and the dynamic portions on the data interface server. The static portions of the database are much larger than the dynamic portions, as queries against static items are more complex and often require the transmission of more data. The dynamic parts of the database are updated frequently. Splitting the central processors into static and dynamic servers optimizes system performance by preventing the complex static queries from affecting the time critical dynamic data updates. This configuration also provides spare capacity on the database server to support the processors necessary for incident detection and automated meter rate selection.

These computers should include a 32-bit processor with high-speed disk drivers, and an industry standard operating system (e.g., UNIX) and Database Management System (DBMS). Examples of current machines that might be used as the central servers include the DEC 6000 and 7000, and the HP9000 series.

Integrated Workstations

All system user access will be through workstations. Workstations will also be utilized for certain specialized processing functions such as VMS control and Expert Systems. In addition to the numerous workstations located in the control center proper (e.g., console room, staff offices), integrated TICC workstations will also be included in each of the agency-specific TOCs and private entity facilities.

The primary objectives of the operator interface are to provide a more effective means for personnel to collect and categorize traffic information, facilitate the interpretation of system information, and provide the ability to quickly formulate solutions to problems that arise. The Boston IVHS network will use an integrated workstation concept to allow common information to be shared across the multiple systems and to provide a common interface to the network. The basic elements of such an interface will include:

- **Map-Based** - The graphic displays generated for the system will be geographically referenced with a map serving as the principal method for navigating through the system. System attributes and devices will be shown as icons overlaid on a geographic representation of the system area with active ties to the database showing information about each element. This geographical representation of the Boston metropolitan area will be a continuous map which can be manipulated by using techniques such as panning and zooming. Typical of the elements that will be monitored through any TICC workstation's user interface are the VMS locations, CCTV, traffic signals, incidents, snow conditions, and traffic information. The map display will be generated from a GIS-based database.
- **Declutter Techniques** - Through the use of de-clutter techniques, the TICC user interface will be able to provide easily readable features at all levels of the system. In general, de-clutter techniques provide a view of major system features, such as highways, transit routes, and symbolic representations of incidents and system components, at views that encompass a large geographic area, and show increasing levels of detail, such as VMS sign message text and interchange geometrics, at views showing limited geography.
- **Graphical User Interface (GUI)** - The information presented on the workstation will be displayed in a combination of formats, including graphical, textual, and video, and will include interfaces to existing and future agency-specific systems. Through the use of standardized graphical user interfaces (GUI) and support products, these various kinds of information can be presented in an integrated fashion. The workstation will provide the ability to execute one or more system applications on the displays and to overlay video images and scanned photographs. This integration of various formats in a windowed environment will allow operators to administer the control aspects of the network while continuously monitoring system components and traffic conditions.
- **Third Party Software** - The correct choice of platform (hardware/operating system combination) will open up the possibility of using familiar third party software for such tasks as system reporting through spreadsheet graphics.

The workstations should be high speed microprocessor based computer systems operating under a multi-tasking operating system (e.g. OS/2 or UNIX) with a full set of software development tools. The system should support an industry standard windowing environment with access to third party support software such as spreadsheets and statistical packages. The workstations should also support the selected IAN networking protocol and DBMS in the client mode. Peripherals will include keyboard mouse, and high resolution color

monitor. Examples of current machines that could be used as TICC workstations include IBM-PCs (486), Sun Microsystems and VAX stations.

VIDEO MONITORING

When analyzing the potential for full CCTV coverage of congested freeways plus spot locations within the Boston metropolitan area, it is readily apparent that not all images can be viewed simultaneously -- both from the standpoint of communications feasibility and from a human factors standpoint. A wall filled with TV monitors showing pictures of traffic may be impressive to the casual observer, but is not terribly useful to the operator. Based on previous control center operations experience, it is estimated that one operator can monitor four CCTV images concurrently.

For verification and monitoring of a single incident and resultant traffic congestion, a minimum of two cameras are typically utilized. These can focus on the incident site plus upstream segments, diversion points, or alternative routes. Given the above human factors considerations, the use of three operators would mean that up to 12 CCTV images could be monitored simultaneously. This would allow for concurrent monitoring of four major incidents. Additional incidents could be monitored through appropriate camera switching functions, including cycling between images at selected intervals.

When a potential incident is identified by the system, the FTMS software will automatically select the proper camera and display the associated video for an operator to check if there is indeed an incident, and if any special response equipment is required. Such functionability can be easily handled by an expert system server. Monitoring of special events can be done by automatically sequencing through a series of cameras.

The final design and analyses will determine the number and location of the required monitors and cameras. In general, it is recommended that 12 each 19/20-inch color monitors be included in MHD control center (for monitoring the freeway network) and in the TICC (for monitoring the region), recognizing that the two sets of monitors will not always be displaying the same images (e.g., video of a minor incident on Rt. 128 will likely not be of interest to the TICC, while video of a problem on the Turnpike will not be a priority to MHD). As a supplement to the CCTV monitors, it is further recommended that the operator

workstations incorporate video insertion capabilities whereby the video from a user-selected camera is displayed (or inserted) in a window superimposed on the workstation screen. As discussed later, the GUI features of the integrated workstation will also permit camera control functions.

It is important that the video subsystem be a shared resource between the TICC and the local TOCs, and the reverse. For example, the TICC should be able to automatically select and access video from any camera located within an agency-specific system for incident confirmation and event monitoring. Similarly, TICC staff may also have pan/tilt/zoom capabilities for these cameras, with local agency override. The system design and CCTV control functions must allow such shared use of cameras (e.g., master camera control at the agency-specific TOCs, with secondary controllers at the TICC) and for the transmission of video images between TICC and TOCs. While some of the workstations may have direct access to analog NTSC video signals, other stations will be limited by the bandwidth of the communications network. In such instances, the use of CODEC (video compression) equipment will allow the efficient transfer of video images between the TICC, agency-specific TOCs.

Other central hardware elements related to video monitoring include:

- Camera controllers for pan, tilt, zoom, focus, washer/wiper, etc. of each camera. These separate devices are in addition to the workstation CCTV control.
- Multiple computer controlled VCRs for taping activities associated with major incidents and special events.
- Date-Time generator to show the date and time, camera number, and a site identification description (e.g., "128 at I-90") on the monitor screens and on any VCR recordings.
- Cable TV Tuners for monitoring weather and other local TV channels for coordinated event management or current events.
- Scan Converters to convert RGB high resolution color graphic displays into NTSC video signals for distribution to local media, Cable TV facilities, and other private entities.
- Video switchers to display the video from specific cameras as selected by the operator, automatically by the system in response to a suspected incident, or

to automatically sequence through a series of cameras. The central video switchers will also provide the means by which remote locations will receive video images.

- Video multiplexing units to enable multiple video images to be multiplexed into a single video image. This is typically a quad multiplexer which allows four video signals (NTSC) to be multiplexed into four separate sub-windows within a single video image.

PROJECTION GRAPHICS

The Boston area IVHS network will rely heavily on the use of real time map technology for situation displays on the integrated workstations. In a typical control center, projection graphics can be used to augment the workstation and video displays. It can also be a valuable tool for the public perception of the situation management. Typically, an RGB switcher will allow any workstation display to be projected for whole room viewing. Multiple video projection displays can be used to present a continuous map of the region or multiple views of a situation.

Since video projection units have replaced typical wall maps, such systems will generally use an imbedded workstation such that the dynamic graphics can be displayed on the projector without requiring the dedicated use of one of the operator workstations. This can also be handled with a graphics server and multiple display drivers depending upon the speed and complexity of the displays. With multiple projectors, one could be used to present the MHD freeway system and the Turnpike, one for Boston's surface streets and MDC network, and one for the MBTA network and other critical locations. In a group of four displays, this would leave one free for large screen video or database displays.

COMMUNICATIONS NETWORK

In a distributed and networked environment, communications between the workstations and the database servers, and between TICC server and TOC server, plays a critical role in the gathering and dissemination of data. The nature of the network structure is such that digital communications between devices is accomplished based on standard

protocols. The communications network at the local level (i.e., individual TOC or TICC) is a Local Area Network (LAN), while the region-wide network between TOCs and the TICC is a Wide Area Network (WAN). A typical network interface configuration for LANs and WANs is Ethernet.

Typical communications services for a networked environment include facilities for file transfer, network file access, remote procedure calls, and data representation. Communication services must serve all of the platforms in the IVHS network, and the communication software must be portable across the various TOC platforms. Several common networks standards have been developed including the IBM System Network Architecture (SNA), the Digital Equipment Corporation DECnet, and the Department of Defense (DOD) Military Standard Protocols. The DOD Protocols have been in use for many years on ARPANET and the Internet. The facilities include TCP/IP (Transmission Control Protocol/Internet Protocol), FTP (File Transfer Protocol), SMTP (Simple Mail Transfer Protocol), and the TELNET Protocol. These standards are supported across many platforms, in many languages, and by many off-the-shelf software packages.

GRAPHICAL USER INTERFACE (GUI)

As previously discussed, the Boston area IVHS network will utilize GUI features and standards to interact with users. Moreover, the display and selection features will be uniform across all TOC platforms and the TICC. Features and mechanisms common to most GUI environments include moveable and/or re-sizable windows with scrollable content regions; pull-down and pop-up menus; and buttons, scrollable lists, entry fields, icons, multiple fonts and intermixed graphics on high resolution displays with operator input provided by mouse and keyboard devices. This user-interface application executes on workstations connected to the rest of the system in a networked manner using standard network protocols.

GUI provides real-time system data in organized text and geo-coded graphical formats. Moreover, using a window mechanism, the data are provided in multiple formats simultaneously. These graphics are not through specific window content design. Many different windows are available to the user, but most fall within the following major

categories:

- Status windows present real-time, text and value-based status on the attributes of a single entity or “object” within the system. These objects may include roadway links (e.g., identification, lanes, current volume and speed, system elements located on the link, etc.), transit links, and each individual system component (e.g., detectors, VMS, CCTV, ramp meter). Attributes can change over time due to data collection cycles, operator input, and event-driven modifications. Status windows always maintain current values of all attributes, updating themselves wherever the state of the corresponding object in the database is changed.
- List windows offer a user-mechanism to view the status of many different objects within a single window in the form of an organized, scrollable list. Most lists contain real-time, updating values -- essentially the same as a status window -- but in a condensed, list-compatible format.
- CCTV video window displays a live video image from a selected camera in most of the window. A portion of the window includes a camera control panel, with azimuth and elevation angle adjustment with predefined valid ranges, and zoom and focus controls. Mouse action on these control icons is translated into camera control commands to the appropriate hardware.
- Incident management windows provide the user-interface mechanisms to assist this process. Windows include a report form (incident type, location, affected links, source, etc.) which is then analyzed by the Expert System to determine whether it correlates with existing reports or is a new incident; incident status and confirmation windows for updating and reviewing incident information and for assigning strategies; incident resource package lists; and response strategy windows which provide a complete description of each incident strategy -- including its objectives, actions, and resource associations -- for operator approval and execution.
- Map windows present the system in a graphical form with accurately geo-coded street and transit segments (links) providing the reference for the position of all system devices, conditions and incidents. Like the status and other windows, the Map View Window content changes in real-time to represent the changing state of the system objects. However, it does not display specific state values, but rather indicates object type and state using color and shape - for example, ranges of average speed on freeway links might be shown as green (50+), yellow (30-50), red (20-30), and flashing red (less than 20). The Map View Window’s geographical format offers the primary user mechanism for displaying the system as a whole, for showing objects with spatial relationships and for summarizing the dynamic state of the IVHS network.

- Online help is available for each primary window. By clicking a question mark icon within the window's corner, a Help Window is created and filled with explanatory text and graphics relevant to the source window.

Examples of a GUI-based operator interface, incorporating several of these windows, is shown in Exhibit 10-6.

After a user has confirmed and managed a few incidents, he or she is likely to have formulated a favorite procedure, and this procedure will involve the creation of certain windows. Rather than require the user to individually create and position each desired window and, subsequently, close each one when a response to the request is submitted, the user-interface should provide a mechanism, called window sets, that does it automatically. A window set is a pre-defined assortment of windows having a related context with pre-defined positions within the workstation screen. As an example, window sets may be available for incident confirmation, strategy approval, and strategy assignment.

With so many windows available, the potential exists for substantial overlapping and obscured views which can frustrate the efforts of the user. While there is no way to entirely avoid window view interference problems, by adhering to certain design rules, the magnitude of the problem can be greatly reduced. Data should be presented in as condensed a format as possible without overburdening the content space or the user's attention. Multiple fonts, highlighting, and other styling techniques may be used to emphasize or de-emphasize where appropriate, and lines or natural dividers employed to separate blocks of similar data categories. The number of windows a user needs to perform common tasks can be reduced by placing all of the most pertinent and related data in one window wherever possible, while placing object and data reference controls as icons in the window to enable more extensive access and investigation by the user when desired (i.e., bringing up a more detailed window as required). The need for many windows is further reduced by the list window mechanism, which allows a user to package the status of multiple objects within a single window that would otherwise have required multiple windows. Finally, the use of pre-defined window sets for frequently performed tasks (as noted above) is a useful tool.

Window-to-window interaction is an important feature of a GUI, as it greatly enhances the friendliness and usability of the user-interface and, therefore, the entire IVHS-based system. Window interaction refers to the capability of the user to cause the contents of one

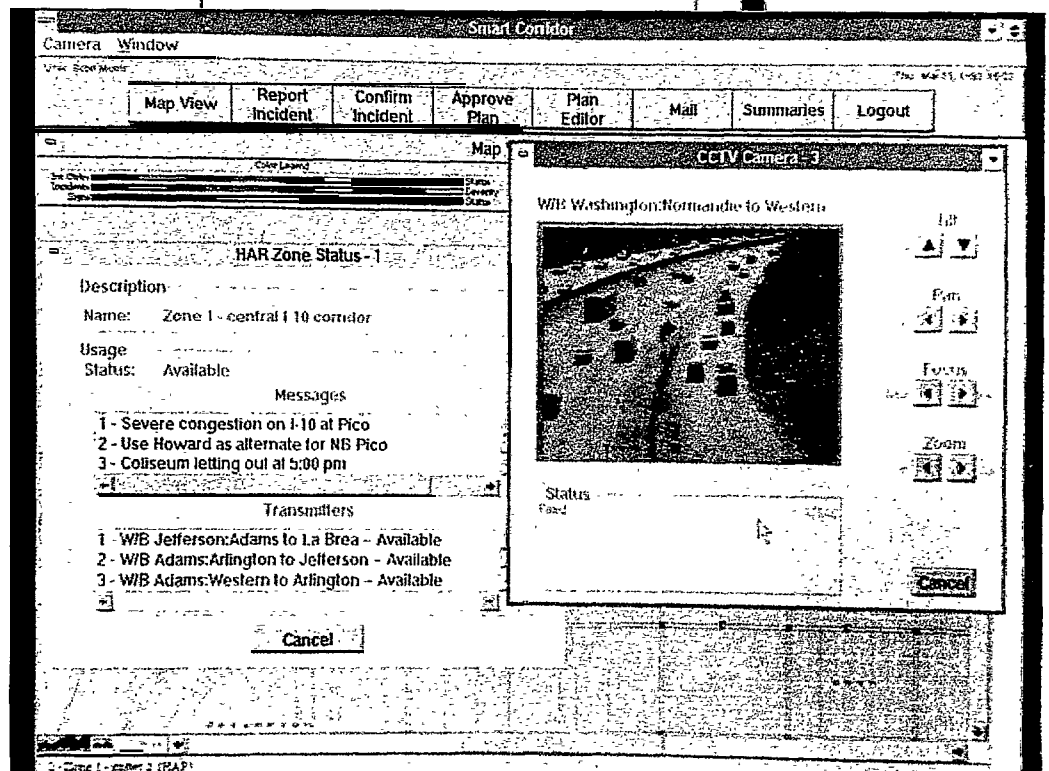
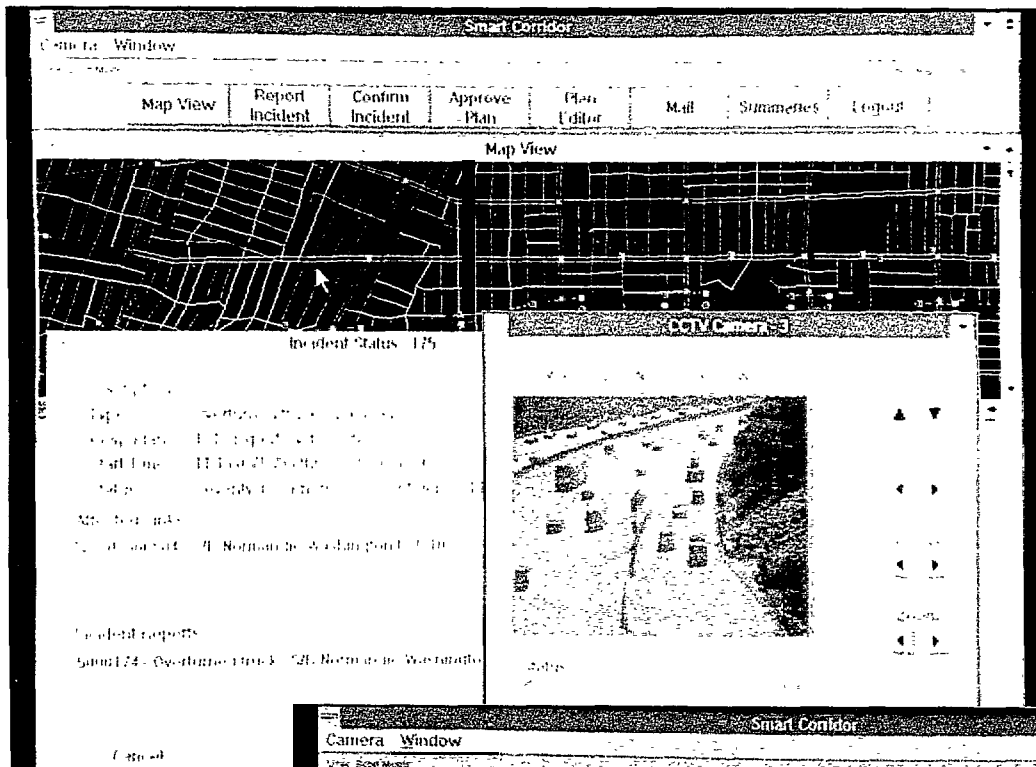


Exhibit 10-6
EXAMPLE OF OPERATOR INTERFACE
(SMART CORRIDOR WORKSTATION)

window to logically affect the contents of another through a specific user action. For example, the user can cause the map to zoom and scroll to show the geographical area surrounding a particular incident, device link, or any other object that appears in another window. Or, the user can add items from a status window to a list window, or create status windows from items in a list. This inter-window interaction support should be designed in such a way as to be flexible and orthogonal -- that is, the user is not limited to certain windows that can interact or certain situations for which interaction is supported. All windows have the potential to interact.

GUI Standards

Several GUI packages have emerged as industry standards. In the PC environment, packages include Microsoft Windows, IBM Presentation Manager, and HP New Wave. In the UNIX and networking environments, the X Window System has become the defacto standard. The X Window System is designed to operate in a networked environment and uses a client-server model to communicate between the display application and the display device. This allows the application to execute either on the local host or a remote host in a manner which is completely transparent to the user. X is also available across a very wide variety of hardware platforms and operating systems, including UNIX, VMS, DOS, and OS2. Stand-alone X display terminals are also available from a variety of manufacturers. Another standard that is under development is IEEE 1201.2 Drivability Recommended Practice. This standard will address window system and graphical user interface functions.

GEOGRAPHIC INFORMATION SYSTEM

The MIS-network database for the Boston metropolitan area will be based on information that is primarily spatial in nature. In fact, spatial considerations are fundamental to most transportation activities. A transportation network can be modeled as nodes, links, and attributes in a two or three dimensional space. Events occur within the framework of this model at a node (an incident, a VMS location, a transit station, toll booth), along a link (vehicle volumes and speeds, pavement condition), or within a buffer of the link

(number of parking spaces in adjacent park and ride lots). Given the large amounts of information that will be input to the TICC from multiple sources (i.e. coupled with the large area of coverage and the need to disseminate the data using a common reference, it is recommended that the IVHS database be organized using a GIS referencing system, with other subsystems (e.g. Expert System, incident management algorithms) accessing the information and performing spatial comparisons.

A geographic information system (GIS) has been defined as a computer hardware and software system designed to collect, manage, manipulate, analyze, and display spatially referenced data. The term GIS commonly refers to an automated system with the distinguishing characteristic of a complex spatial data processing capability. Spatial data is any type of data which can be assigned or referenced to the Earth's surface (i.e., latitude/longitude coordinates), or a similar set of Cartesian coordinates. The most common example of spatial data is graphic information from a paper map such as roads and city boundaries. GIS's are additionally able to process textual information which describes a graphic feature. A graphic line or vector representing a road, for instance, can have associated with it various attributes which further describe the road, such as surface type, speed limit, traffic volume, and direction of travel. These attributes are usually stored in a Database Management System with links to the graphic feature. In the last few years, other types of data such as digitally scanned documents and video images have also been associated with spatial data.

GIS technology can provide the framework for an integrated transportation network within the Boston region. The spatially referenced indexing used with a GIS provides a common foundation for the sharing of aggregate information within and across transportation agencies. GIS can integrate data from many different sources, thereby providing an effective means for TICC and TOC personnel to collect and categorize traffic and transit information, interpret and analyze the information, aid in problem resolution, and integrate spatially related data from other agencies for interagency analysis purposes.

Exhibit 10-7 presents several functions for GIS within the IVHS network. The initial (i.e., Phase 1) functions will involve geographically organized information which is shared between agencies and the private sector querying the TICC in a spatial (map-based) manner, and facilities management techniques to aid in the maintenance of field components.

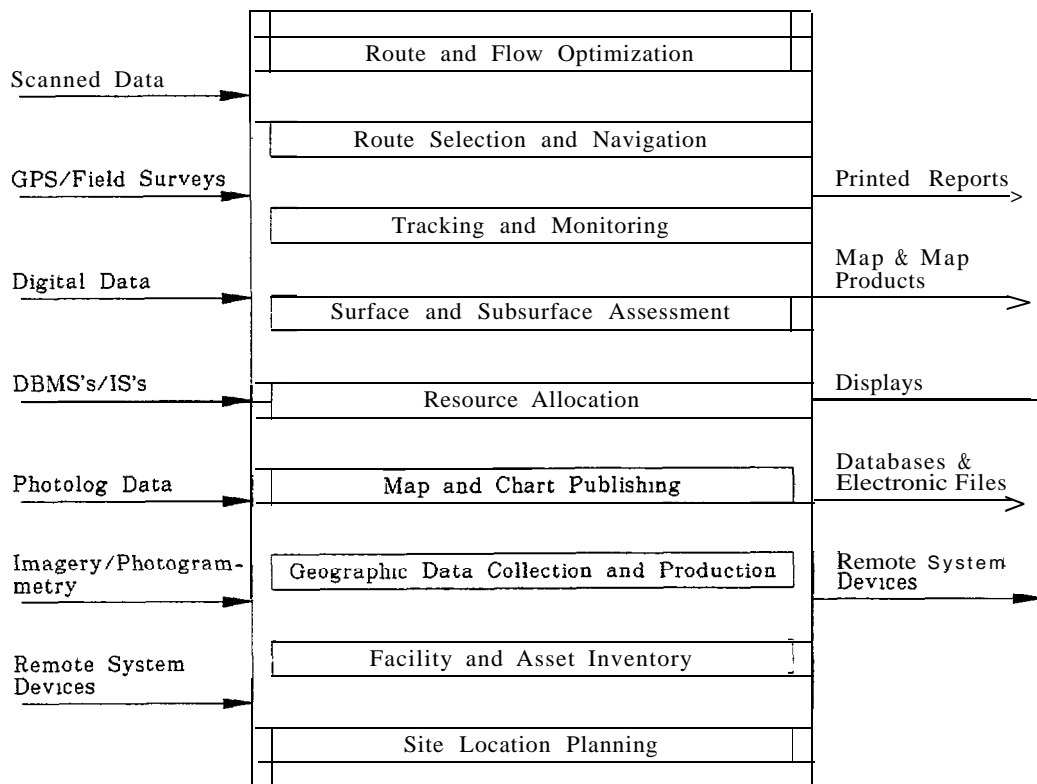


Exhibit 10-7: Basic GIS Functions in an IVHS Application

Not only can GIS play an important role in the initial development of a regional IVHS network, it can also provide an evolutionary step toward future IVHS elements. For example, the digital base map and spatial/temporal data models facilitate the capability of an IVHS to perform navigation and control processing for vehicles in real-time. The spatially referenced structure of the GIS provides a data foundation for real-time analysis of IVHS remote monitoring and control devices, including in-car navigation equipment. GIS will also be an important element in route and mode optimization -- the spatial database of GIS being queried by advanced algorithms to arrive at the optimum state for traffic flow under historical and real-time constraints.

During the design of the central hardware and software, several GIS issues will need to be resolved, including:

- GIS software (e.g., ARC/Info, Intergraph, GDS; off-the-shelf vs custom; compatibility with existing GIS networks as used in other transportation management systems within the region).
- Performance requirements (i.e., speed) such that real-time events are processed, transferred, and displayed in a time critical fashion to accurately represent the event and its on-going status.
- Data management (i.e., information contained in individual layers of database).
- Base mapping (i.e., source, scales, resolution, accuracy>).

DECISION SUPPORT

The configuration of the Boston area transportation network is such that incident management procedures and potential traffic management strategies will undoubtedly affect multiple agencies. One of the primary functions of the regional TICC is to implement coordinated and pre-approved strategies and response plans to such events, including confirmation from the various transportation agencies that elements under their respective control have been deployed in accordance with the response plan. This decision-making process can be facilitated through the use of a decision support mechanism which accesses the full range of policy and pre-approved response information (static information), and

compares it with real-time traffic information. The quick correlation of incident reports and observations can lead to a more rapid incident confirmation which, in turn, allows the appropriate response strategy to be established more quickly. Moreover, the decision support mechanism can expedite the deployment of the response plan (e.g., notifications, VMS, dispatch of incident teams, etc.)

Another consideration is system size. As the Boston area IVHS network grows to encompass the region, the amount of data and coordination of individual response plans will exceed the capabilities of staff if performed in a manual fashion. In addition, as there will be staff turnover, vacations, and other unplanned absences, it is necessary to construct a powerful decision support mechanism which embodies the normal decision-making “intuition” of these operators. To meet this problem and provide rapid response, it is recommended that an Expert System be employed for decision support and incident management.

A “knowledge-base” may be thought of as the set of knowledge and relevant information needed to solve problems of a particular problem domain. For example, the predefined set of procedures and data to detect an incident on a freeway represents an established knowledge-base. A knowledge-base may be presented as flow charts, decision tables, computer programs, or simply a series of “IF’-THEN-ELSE” statements. When a knowledge-base is well defined and understood, it is possible to construct a computerized “expert system” to solve problems in a particular domain at a level comparable to a human expert. As used here, the terminology “knowledge-based expert system” (KBES) is defined as the hardware and software complement needed to provide one or more of these computerized “expert systems” at a given location within the regional IVHS network.

An Expert System will provide operator decision support for several functions:

- Incident detection and verification - The system correlates information received from multiple sources such as freeway sensors, police reports, current transit schedules, the location of incident response teams, cellular radio reports, etc. to establish the presence of an incident. This information is formatted and presented to an operator for confirmation. The system may activate cameras and provide images to corroborate the information from other sources.
- Identification and evaluation of alternative responses - With knowledge of the network, the devices available, and the basic pre-approved plans, the Expert System can recommend the appropriate responses to an incident such as signal

timing plan changes, ramp metering rates, and VMS message displays, and then present this information to operators for approval or modifications as may be appropriate. The Expert System can also assist in executing the response plan by sending messages to the appropriate agencies to actuate field devices (if control of these devices has not been provided to the TICC).

- Checklist procedures - The expert system will present checklists as an aid in reminding the operator of required notifications, actions, clean-up, and follow-up based upon incident type.
- Motorist information - As part of the response plan, the Expert System can identify information to be transmitted to the media and other private entities.

Even after the incident response plan has been put into effect, the KBES will continue to monitor the traffic network status for changes and recommend additional responses or terminate previous responses. Exhibit 10-8 shows a typical configuration including an expert system server for incident management. It should be noted that the diagram suggests that the expert system server is a separate computer connected to the system via the Wide Area Network (WAN). It could also be a separate process running on any of the TICC hardware depending upon the Expert Shell environment and the memory and processing time available. All of these will be determined during the system analysis.

The Rule Base (i.e., pre-approved plans) will be developed through an extensive process of operational planning involving TICC staff and representatives of the Advisory Committee agencies. Policies will be established for specific diversion routes, signal timing at key locations, VMS messages, and other operational concerns. Such information will be coded as “rules” -- via a strategy creating and editing window of the GUI -- and will contain operational threshold values for various traffic measures which will identify themselves when a response is required.

The dynamic database (the Knowledge Base), which extracts real-time data from the appropriate agency-specific systems across the Boston IVHS network, will provide the Expert System with the parameter values necessary to perform trade-off analyses and comparisons, and synthesize appropriate strategies and actions that are then presented to the various agencies for approval. The recommendation could either be accepted in full by all the individual TOC's or modified based on additional real-time knowledge (i.e., weather, unscheduled special events) not ascertained by the Expert System. Based on this, the

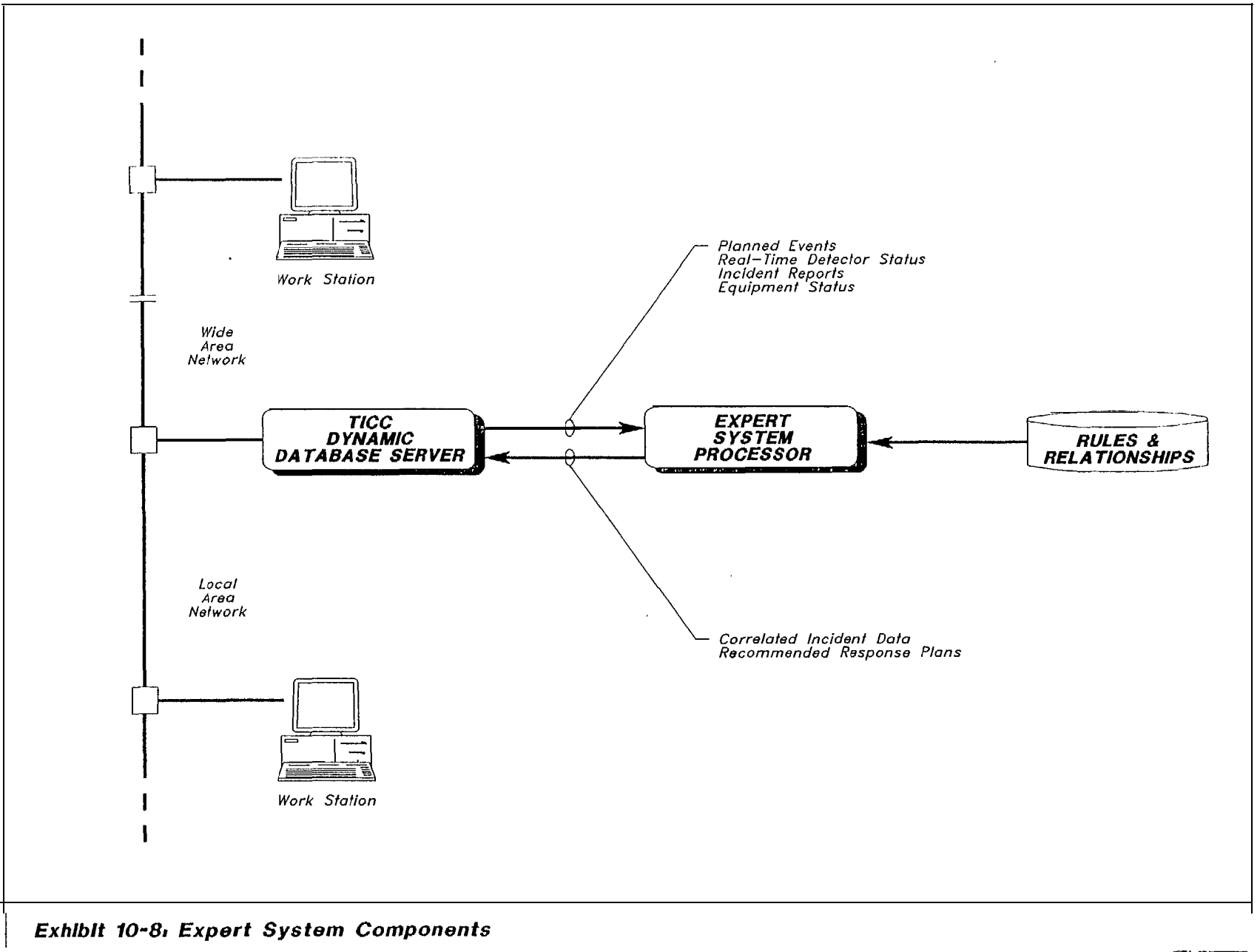


Exhibit 10-8. Expert System Components

appropriate strategies are then sent automatically to the appropriate agency-system elements for implementation without the need for further operator intervention. The Expert System also could provide the means for conflict resolution between different agency policies or strategies which do not support one another.

SOFTWARE

The IVHS network for the Boston Region presents a challenging set of requirements for system software analysis, design, and development. The system is envisioned as a heterogeneous, open system featuring many different hardware and software platforms, presenting a uniform and consistent interface to the users of the system. Developed to Open System standards, the IVHS network software should feature the use of standard protocols and procedures in order to facilitate integration of new functionality and features to the system by developers who adhere to the standards. The system architecture must be amenable to expansion as new geographical areas are added to the system. The architecture must also be flexible to enable seamless integration of new functionality as operational concepts and requirements evolve. This will be especially critical as additional components and future functions of the M-IS are integrated into the operations.

To maximize compatibility with other systems and future functions, software development should incorporate Open System Environment standards. Many of these standards are being developed under the banner of the IEEE portable operating system interface (POSIX) environment. POSIX standards are generally directed toward operating system services. Other standards developed by ANSI, ISO, and others address more specialized areas such as programming languages, databases, and communication protocols. In combination, all of these standards contribute to the major goal of open systems development: to enhance the portability and the intersystem operability of software.

The POSM OSE standards define two types of standard interfaces: the Application Program Interface (API) and the External Environment Interface (EEI). APIs are procedure calls made to the platform on which an application is running. These calls may interact with the operating system, system utilities, or other applications. In an IVHS network these calls might include database transactions and file transactions between TOC systems and TICC.

EEIs are connected to the external environment, which is often defined to include external devices such as printers, graphical displays, disks, and networks. In the IVHS environment, the external environment will also include detector processors, variable message signs, CCTV cameras, and other hardware.

As the POSIX standards are developed, many are being adopted by major vendors and incorporated into their products. Unfortunately, many of the standards that will be required for a truly complete Open System Environment are only in the earliest stages of development. A very significant example is the standard on network communication services which is not expected to be completed until the latter part of this decade. In such cases, the recommended approach is to utilize current industry standards which will continue to be supported into the future due to their current large client bases. Then, as standards are completed and incorporated into the operating system releases by major vendors, they may be introduced into the Boston area systems. It is, therefore, critical that operating system and utility package software support be maintained with the major vendors to facilitate the eventual migration to an Open System Environment.

FTMS Software

The system software features previously discussed -- database management, graphical user interface, GIS, Expert Systems, etc. -- are applicable at both the TOC level (e.g., MHD, FTMS) and the TICC, with the Expert System being resident at the TICC in terms of processing and developing/editing response strategies. The MHD - FTMS software will also encompass the basic control concepts and system functions as described in previous chapters. It is anticipated that the FTMS software will include the following:

- Local processing and storage of detector data.
- Detector, ramp meter, VMS and communications diagnostics, and related failure analysis including operator alarms.
- Calculations for periodic measures of performance for the freeway system.
- Data logging and retrieval.

- Report generation.
- Maintenance analysis (e.g., mean time between failures of devices).
- On-line simulation and forecasting.
- System security.
- Background processing (auxiliary programs).

Neural Network Technology

A neural network is a massively parallel information processing unit which is composed of many simple elements interconnected to achieve collective computational capabilities. Information and procedures -- such as those required for the Boston area M-IS network -- are stored in a distributed fashion throughout the interconnected system. Artificial intelligence research suggests that the idealized neural network and model possesses many properties similar to those of the human brain. Neural networks can efficiently "solve" (i.e., quickly obtain nearly optimal solutions) certain optimization problems which are difficult to solve using traditional algorithmic techniques. Also, neural networks can be programmed to "behave" adaptively (learn by example). Due to their parallel processing characteristics, neural networks may provide the answers to many of today's formidable data processing problems. In addition, their "learning" abilities offer opportunities for providing more adaptive real-time simulation and control systems and for automating many of the human tasks which are not practical to automate using traditional techniques.

Neural network technology offers future potential (i.e., Year 2000 Plan) for delivering unique solutions to many of the Boston area transportation management issues. Some of the specific areas where neural networks may be applicable include: adaptive incident detection, traffic demand prediction and simulation, on-line incident response plan optimization, and device failure monitoring.